Aeroelastic Stability Testing

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An important consideration in the design of helicopter rotor blades is the stability of the isolated rotor and the coupled rotor-body system. Once disturbed, unstable linear systems grow in response without bound until a failure occurs. Therefore, the helicopter design engineer would like an analytical tool that would accurately calculate the stability of these systems. The present work provides an experimental database that is needed to validate these analytical tools. The database, when complete, will include two rotor-blade configurations tested in hover and forward flight. This year's accomplishments include the fabrication and structural testing of the second rotor-blade configuration.

The two configurations include a rectangular blade with center of gravity, elastic axis, tensile axis, and aerodynamic center located on the quarter chord, and a swept-tip blade with small offsets in elastic and inertial properties. The rectangular blade is the simplest of the two structures to analyze. The more complicated swept tip amplifies the coupling of bending and torsion modes. Both blade sets have a hingeless hub design (root pitch motion through a feathering bearing; flap and in-plane motion through a composite root flexure). The rotors are mounted on a relatively rigid test stand to confine the experiment to the physics of interest. Once the operating condition is obtained, hydraulic actuators are used to oscillate the pitch of the blade at the regressive in-plane mode natural frequency, thus exciting this lowly damped mode. The excitation is shut off and the decay of the in-plane bending moment is measured by strain gages bonded to the blade structure. The rectangular-bladed rotor has been tested in hover by varying rotor speed and collective pitch and in forward flight by varying wind speed, collective pitch, and shaft angle at 1700 revolutions per minute.

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Flight Mechanics of Helicopter Sling-Load Systems

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The specific objectives of this research are (1) to develop and demonstrate the ability to compute the dynamic flight envelope of helicopter and sling-load combinations simultaneously with flight testing, and (2) to develop corresponding simulation models validated with flight-test data.

Helicopter sling-load operations are common in both military and civil operations. The addition of the load can degrade system stability and reduce the safe operating envelope of the combined system below that of the helicopter alone. During its operational life, a utility helicopter will carry a wide variety of loads using a variety of slings, each with different dynamic characteristics. Incidents and accidents can occur when the dynamic limits of the helicopter and load are unknowingly exceeded. To avoid these occurrences, military helicopters and loads are usually qualified for these operations in flight tests, which can be expensive, time consuming, and sometimes risky.

The cost, time, and risks of flight qualification tests can be reduced by developing a system providing real-time analysis of flight-test data. Quantitative assessment of helicopter flying qualities and load-pendulum stability can be accomplished after a test at a given test airspeed and before proceeding to the next test point. Further, the ability to make reliable predictions of load-helicopter stability from simulation models will reduce the requirement for flight-test qualifications to just a few loads, provide knowledge of critical points in advance of flight testing, and allow assessment of loads for which flight-test evaluations are not available.

Flight tests were conducted with an instrumented UH-60A Black Hawk helicopter and an 8- by 6- by 6-foot standard military cargo container. The first figure shows the helicopter carrying its instrumented load. Data were telemetered to a ground station where they were analyzed by using three work stations interfaced with the real-time telemetry system. The computations and the subsequent engineering and safety assessments took 4–8 minutes to complete before the pilot was cleared to proceed to the next test point.

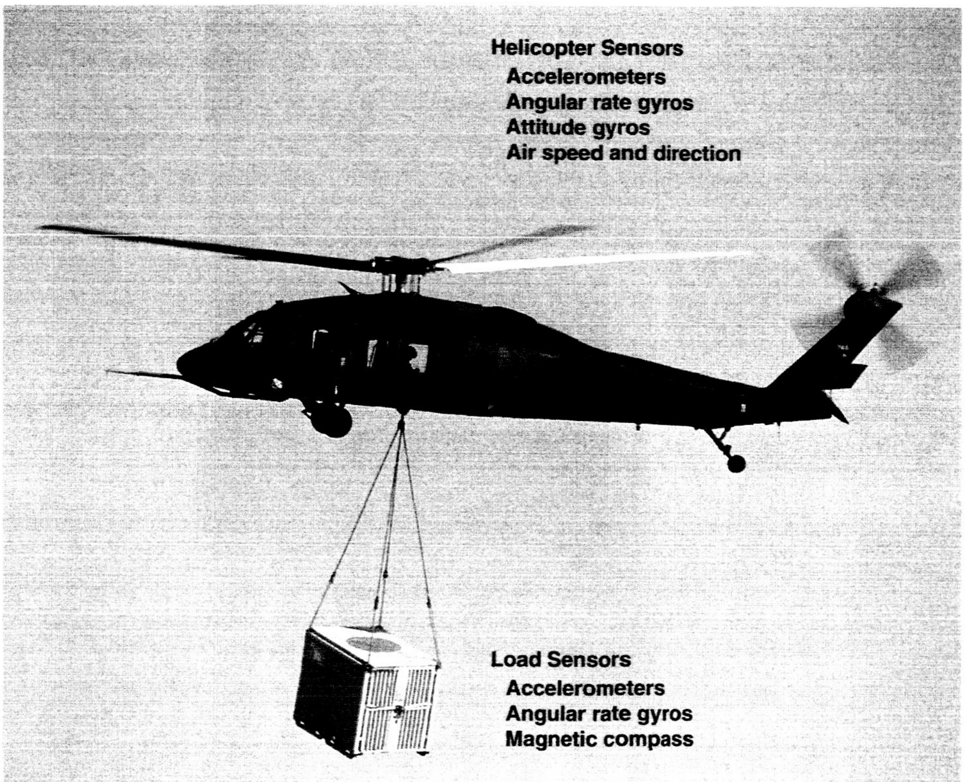

Fig. 1. Black Hawk helicopter with Conex box load.

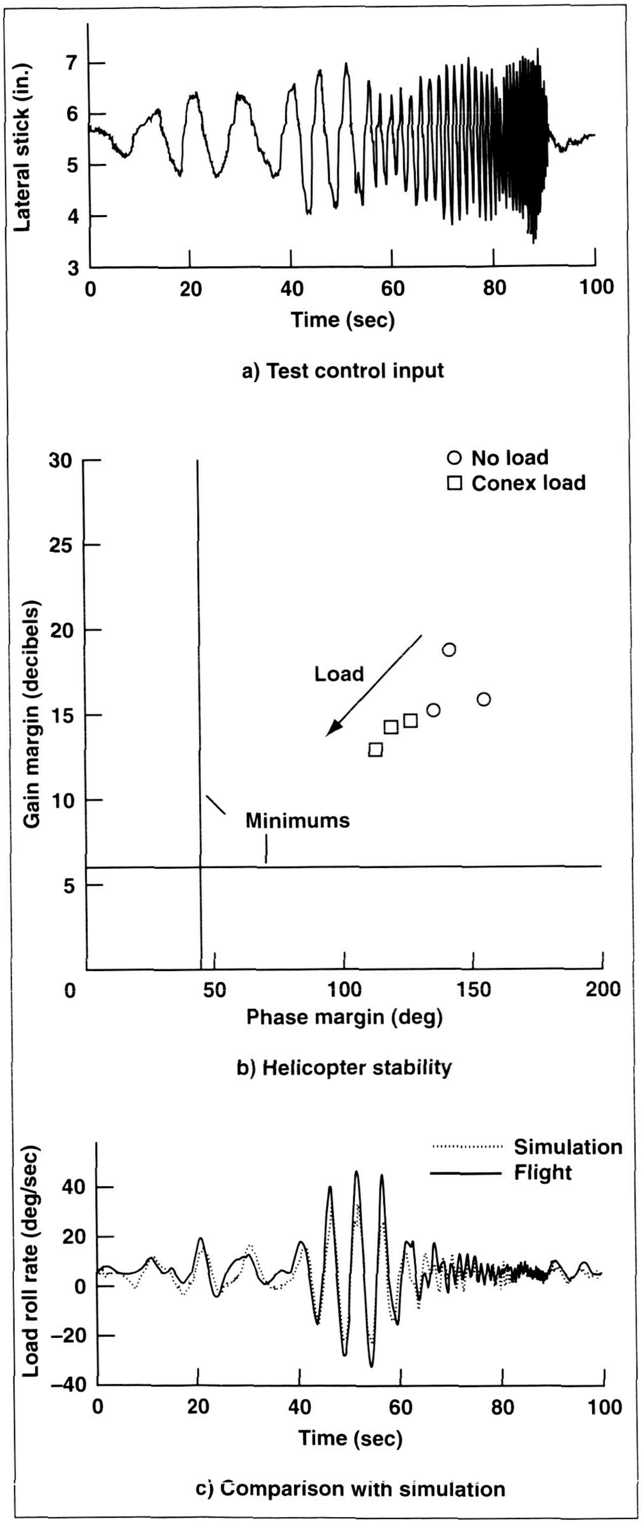

Fig. 2. (a) Pilot's test control input; (b) helicopter stability with and without Conex load; (c) comparison with simulation—load roll rate.

The analysis used the CIFER™ software for frequency-domain analysis of flight data. This flight-test software tool was developed previously at Ames. The top portion of the second figure (test control input) shows the sinusoidal control inputs of increasing frequency from 0.05 to 2 cycles per second, which the software uses, along with the corresponding roll response of the helicopter, to calculate phase and gain stability margins of the helicopter-load combination. Results are shown in the middle part of the figure (helicopter stability). A moderate reduction in stability margins at three test airspeeds—hover, 30 knots, and 50 knots—is indicated when the helicopter is carrying the load. Although the Black Hawk has ample available margin above the safe minimums, other load-carrying helicopters do not, and for such aircraft the loss in stability margin seen here could pose a risk.

The load instrumentation package was provided by the Technion (Israel Institute of Technology) under a U.S. Army/Israel memorandum of agreement. It was designed for portability, and provides comprehensive data on the details of load motions—possibly the first such data available for systematic validation of mathematical models of the load-sling motions. The bottom of this second figure (comparison with simulation) shows a sample comparison of flight and simulation responses for load roll rate during a lateral-axis control frequency sweep. There is good agreement in this comparison. However, other data and observations indicate that significant improvements in simulation models are still required to fully predict the helicopter and load motion.

A total of 15 data flights were recorded and archived as a database for simulation validation.

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